NASA/TM—2014-218316

General Dynamic (GD) Launch Waveform On-Orbit Performance Report

Janette C. Briones and Mary Jo Shalkhauser
Glenn Research Center, Cleveland, Ohio

December 2014

NASA STI Program . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) program plays a key part in helping NASA maintain this important role.

The NASA STI Program operates under the auspices of the Agency Chief Information Officer. It collects, organizes, provides for archiving, and disseminates NASA's STI. The NASA STI program provides access to the NASA Aeronautics and Space Database and its public interface, the NASA Technical Reports Server, thus providing one of the largest collections of aeronautical and space science STI in the world. Results are published in both non-NASA channels and by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.

- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.

- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.

- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.

- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.

- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services also include organizing and publishing research results, distributing specialized research announcements and feeds, providing information desk and personal search support, and enabling data exchange services.

For more information about the NASA STI program, see the following:

- Access the NASA STI program home page at *http://www.sti.nasa.gov*

- E-mail your question to *help@sti.nasa.gov*

- Phone the NASA STI Information Desk at 757-864-9658

- Write to:
  NASA STI Information Desk
  Mail Stop 148
  NASA Langley Research Center
  Hampton, VA 23681-2199

NASA/TM—2014-218316

General Dynamic (GD) Launch Waveform On-Orbit Performance Report

Janette C. Briones and Mary Jo Shalkhauser
Glenn Research Center, Cleveland, Ohio

National Aeronautics and
Space Administration

Glenn Research Center
Cleveland, Ohio 44135

December 2014

Level of Review: This material has been technically reviewed by technical management.

Available from

NASA STI Information Desk
Mail Stop 148
NASA Langley Research Center
Hampton, VA 23681-2199

National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312

Available electronically at http://www.sti.nasa.gov

General Dynamic (GD) Launch Waveform On-Orbit Performance Report

Janette C. Briones and Mary Jo Shalkhauser
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio 44135

Abstract

The purpose of this report is to present the results from the GD SDR on-orbit performance testing using the launch waveform over TDRSS. The tests include the evaluation of well-tested waveform modes, the operation of RF links that are expected to have high margins, the verification of forward return link operation (including full duplex), the verification of non-coherent operational models, and the verification of radio at-launch operational frequencies. This report also outlines the launch waveform tests conducted and comparisons to the results obtained from ground testing.

Introduction

The objective of the Space Communications and Navigation (SCaN) Testbed is to investigate the applicability of software defined radios (SDR) to NASA missions and to study the operation of SDRs and their waveform applications in an operational space environment. Developed at NASA's Glenn Research Center, the SCaN Testbed is an experimental communication system that provides the capability for S-Band, Ka-Band, and L-Band communication with both space and ground assets. The SCaN Testbed was launched on July 20, 2012, and is installed on the International Space Station (ISS) (Fig. 1). The SCaN Testbed contains three SDRs which are reprogrammable and are running waveform applications that enable reconfigurability. The testbed provides experimenters an opportunity to develop and demonstrate experimental waveforms in space to reduce cost and risk for future space missions using SDRs, and to develop and test experimental waveforms.

One of the radios was developed by General Dynamics (GD) (Fig. 2). The GD SDR is an S-Band Tracking Relay Data Satellite System (TDRSS) fourth-generation transponder. The GD SDR supports full-duplex communications at S-band frequency. The S-band capabilities of the radio have been tested with NASA's Tracking and Data Relay Satellite System (TDRSS) network of geosynchronous satellites.

The GD SDR launch waveform was installed on the GD SDR prior to launch to ISS. This waveform is compliant with the capabilities of TDRSS and allows the radio to support full-duplex communication with a Tracking and Data Relay Satellite (TDRS). The waveform is compliant with the Space Telecommunications Radio System (STRS) architecture standard.

Prior to the launch of the SCaN Testbed, an extensive set of communications tests was performed with the GD SDR for the verification of application requirements and for SDR characterization. These tests included functional and performance testing of the engineering model (EM) and the flight model (FM) versions of the GD SDR. These tests were performed at the Glenn Research Center (GRC), and included vibration tests, thermal vacuum (TVAC) tests, and electromagnetic interference (EMI) tests. The GD SDR Data Book (SCaN Testbed project document GRC-CONN-RPT-0917) details the results of the GD launch waveform performance during ground testing. This set of performance data will be used as a baseline for evaluating the on-orbit performance of the radio.

Figure 1.—SCaN Testbed Installed on ISS.

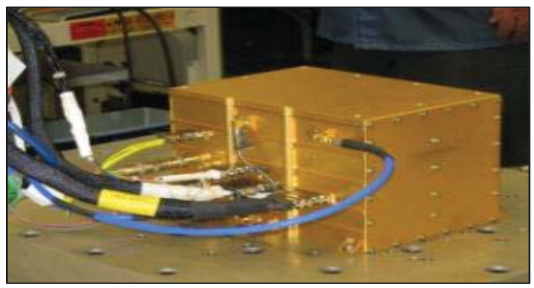

Figure 2.—GD Software Defined Radio.

TABLE 1.—GD SDR RECEIVE WAVEFORM DESCRIPTION

Waveform Number	Center Frequency	Data Rate (kbps)	Forward Error Correction (FEC)
180/182	SA	18	Uncoded
179/181	SA	18	Coded
184/186	MA	18	Uncoded
183/185	MA	18	Coded
204/206	SA	72	Uncoded
203/205	SA	72	Coded
208/210	MA	72	Uncoded
207/208	MA	72	Coded

The GD SDR receive waveform includes several reconfigurable parameters which include data rate, coding enable/disable, and center frequency. The receive waveform is a spread signal and is compatible with the Tracking Relay Data Satellite System (TDRSS). The S-Band RF center frequency can be changed to operate with the TDRSS Single Access (SA) or Multiple Access (MA) modes. The receive waveform also can be configured to operate at 18 kbps or 72 kbps data rates. The Viterbi decoder for forward error correction decoding can be enabled and disabled. These three parameters lead to the eight receive waveform combinations as shown in Table 1. For the SCaN Testbed operations, a unique transmit and receive waveform configuration was given a unique waveform number.

The purpose of this report is to present the results from the GD SDR on-orbit performance testing using the launch waveform over TDRSS. The tests include the evaluation of well-tested waveform modes, the operation of RF links that are expected to have high margins, the verification of forward/return link operation (including full duplex), the verification of non-coherent operational models, and the verification of radio at-launch operational frequencies. This report also outlines the launch waveform tests conducted and comparisons to the results obtained from ground testing.

GD Launch Waveform On-Orbit Tests

Launch waveform characterization test were designed to understand the performance of the GD SDR in a flight environment. Variations of the tests were used to test the medium gain antenna (MGA) path, the single access (SA) and multiple access (MA) frequencies, coded and uncoded data, a variety of data rates, and non-coherent waveforms. During Launch Waveform Testing, 23 TDRSS events were conducted. The selected waveform configurations were chosen to exercise a variety of the waveform's reconfigurable parameters and to give the best performance (i.e., the waveforms with the best link margins). Table 2 shows a list of the test events using the launch waveform in an operational environment with the best performing waveforms.

A full list of the launch waveform test performed including full system and waveform configuration and test objectives can be found in Table 7, Launch Waveform Test Matrix, in Appendix A. The mission operations team used these tables to generate their operational procedures and schedule events with the space network (SN).

During the commissioning phase of on-orbit tests, the GD SDR was operated under typical mission-like antenna pointing and power conditions. Twenty-seven TDRSS events were completed. During these tests the RF link margins were verified and found to be performing as expected, according to the GD Space Network Link Book described in the GD SDR Commissioning Report (SCaN Testbed project document GRC-CONN-RPT-1020 APPENDIX C).

All tested waveforms met or exceeded the expected bit error rate performance. A variety of waveforms were utilized so that all waveform characteristics (antenna, RF path, data rate, encoding/decoding, center frequency, internal BER, SpaceWire/Avionics BER, framing/deframing, etc.) could be tested on-orbit. All the TDRSS modes (DG1 modes 1, 2 and 3; and DG2) implemented in the GD radio were exercised.

Every test was completed at least two times to verify that the results were repeatable. A summary of the waveform configurations for the commissioning tests and the test results are shown in Table 3. This summary table shows the expected BER performance and the BER performance demonstrated on-orbit.

TABLE 2.—LAUNCH WAVEFORM TESTING EVENTS SUMMARY

Test	Antenna	Freq.	Links	Coherent	Forward Rate	Return Rate	SpW	FEC	Status
Test 20	SN-MGA	SA	Full-Duplex	No	18 k	24 k	No	No	Passed
Test 21	SN-MGA	MA	Full-Duplex	No	18 k	24 k	Yes	Yes	Passed
Test 22	SN-MGA	SA	Full-Duplex	Yes	72 k	192 k	No	No	Passed
Test 23	SN-MGA	MA	Full-Duplex	No	72 k	192 k	Yes	No	Passed

TABLE 3.—COMMISSIONING AND LAUNCH WAVEFORM TESTING EVENTS SUMMARY

	Antenna	Freq.	Links	Coherent	Forward Rate	Return Rate	SpW	FEC	Expected BER		Actual BER		Status
									FWD	RTN	FWD	RTN	
Test 6	SN-MGA	SA	Full-duplex	No	18 K	24 K	No	Yes	0	0	0	0	Passed
Test 7	SN-LGA	MA	Full-duplex	No	18 K	24 K	Yes	No	6×10^{-3}	8×10^{-3}	4×10^{-5}	4×10^{-4}	Passed
Test 8	SN-MGA	SA	Full-duplex	Yes	72 K	192 K	No	No	0	0	0	0	Passed
Test 8b	SN-MGA	SA	Full-duplex	Yes	72 K	1 M DG1M3	No	No	0	*	0	10^{-3}	Passed
Test 8c	SN-MGA	SA	Full-duplex	No	72 K	1 M DG2	No	No	0	*	0	10^{-4}	Passed
Test 9	SN-MGA	MA	Full-duplex	Yes	72 K	192 K	Yes	No	0	*	0	**	Passed
Test 9b	SN-MGA	MA	Full-duplex	Yes	72 K	192 K	No	Yes	0	*	0	**	Passed
Test 10	SN-MGA	SA	Full-duplex	Yes	72 K	192 K	Yes	Yes	0	0	0	0	Passed

*Not expected to acquire.

**Could not acquire.

All commissioning forward-link tests met or exceeded the expected performance. All SN-MGA forward-link tests resulted in a bit error rate of zero, as expected, due to the high power at the input to the SDR. The SN-LGA forward-link, in contrast, had a much lower link margin and the SDR experienced bit errors in the data during the entire event (Test 7). Every test on the return-link met or exceeded the expected bit error rate performance. Table 3 shows that the return-link for the SA 24 kbps and 192 kbps events (Test 6, 8, and 10) achieved a BER of zero over the duration of each event. Test 7, the SN-LGA event, achieved a 4×10^{-4} BER averaged over the event length due to the lower gain and lower link margin. The high data rate (1 Mbps) events (Tests 8b and 8c) achieved an average BER of 10^{-3} and 10^{-4}, respectively. This BER was better than expected, since the link margin was not expected to be high enough to close the link. The two 192 kbps, MA events (test 9 and 9b) did not have enough power for the receiver at White Sands to acquire a signal and achieve a BER.

Antenna Off-Pointing

During launch waveform testing, full characterization of the on-orbit performance of the GD SDR required the radio to operate at power levels other than those typically provided by White Sands and the TDRSS spacecraft(s). A wide range of power levels at the input to the GD radio was desired in order to capture on-orbit data. The input power to the GD SDR was varied using purposeful antenna off-pointing allowing the experimenters to gather full BER curves, radio acquisition level data, and digital and analog automatic gain control (AGC) data.

Early profiles as shown in Figure 3 were designed to start the input power level below the SDR acquisition level and raise it to the point where zero bit errors would be seen. Then the power would be lowered again past the point where the radio would be expected to lose acquisition. This style of profile worked well for acquiring BER data, but was not good for acquisition levels. The profiles were designed for 40 min TDRSS events, but the actual events often were as short as 20 to 30 min.

During testing, it was determined that it was easier to find the point where the radio loses acquisition, rather than the point where it acquires. When the GD radio reaches state 5 in its acquisition state machine, it is acquired enough to receive data. It was difficult to know emphatically at the beginning of an event when the radio reached state 5 if it was because it just got the minimum amount of power to reach state 5, or if it had more than enough power and had to transition through all the states to reach state 5.

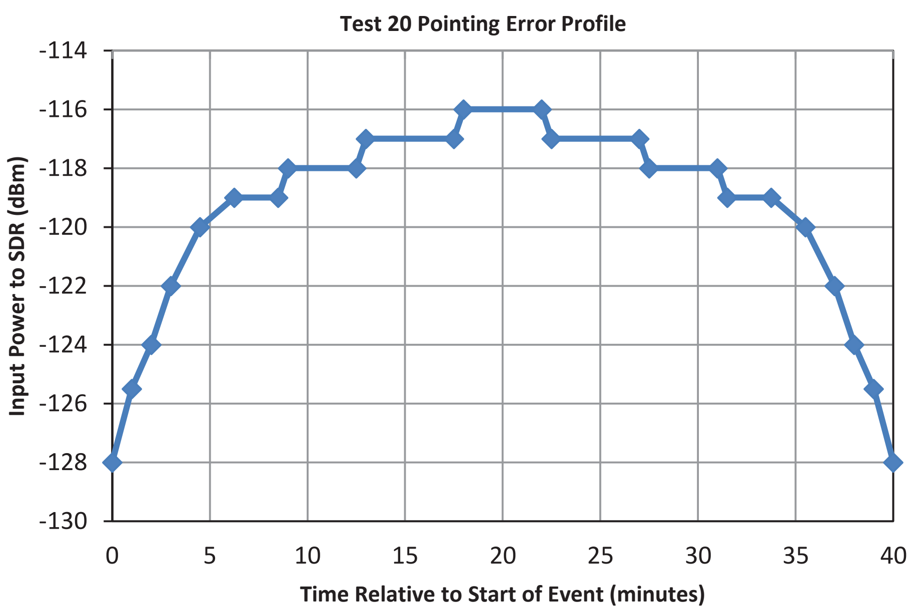

Figure 3.—Profile Style 1.

As the GD receiver acquires a signal, it progresses through a state machine with the 6 states whose functions are described in Table 4.

All the TDRSS events using the profile style shown in Figure 3 were never long enough to reach a power low enough as shown in the second half of the profile in Figure 3 to lose acquisition during the second half of the profile. Figure 4 shows the actual achieved profile during one particular event. This figure shows the predicted power and the estimated power obtained during that event.

TABLE 4.—RECEIVE WAVEFORM STATES

Receive Waveform States	Functions
1 – Search	The SDR is searching for a RF input signal, but it does not see any power. The PN code is being swept to correlate with the received signal.
2 – AGC Normalization/PN Code Loop Acquisition	Both the digital and analog AGC gain is being set. During this state the code tracking loop is locking to the received short code.
3 – PN Code Lock Detection/Sidelobe Search	The receiver has begun tracking the short code and is now looking for the PN lock detector to indicate lock. At the same time, the SDR searches the PN code again for higher power on sidelobe, looking for a correlation with more signal energy. If one is found, the initial lock was to a sidelobe.
4 – PN Code Locked/Carrier Acquisition	The PN code is locked and the carrier is being acquired.
5 – Carrier Locked/Long Code Acquisition	The carrier is locked and the SDR is trying to acquire the long PN code. The bit sync will be locked in this state and BER measurements can be made.
6 – TDRSS Mode Tracking	The carrier, PN code, and Long code are locked and the SDR is tracking.

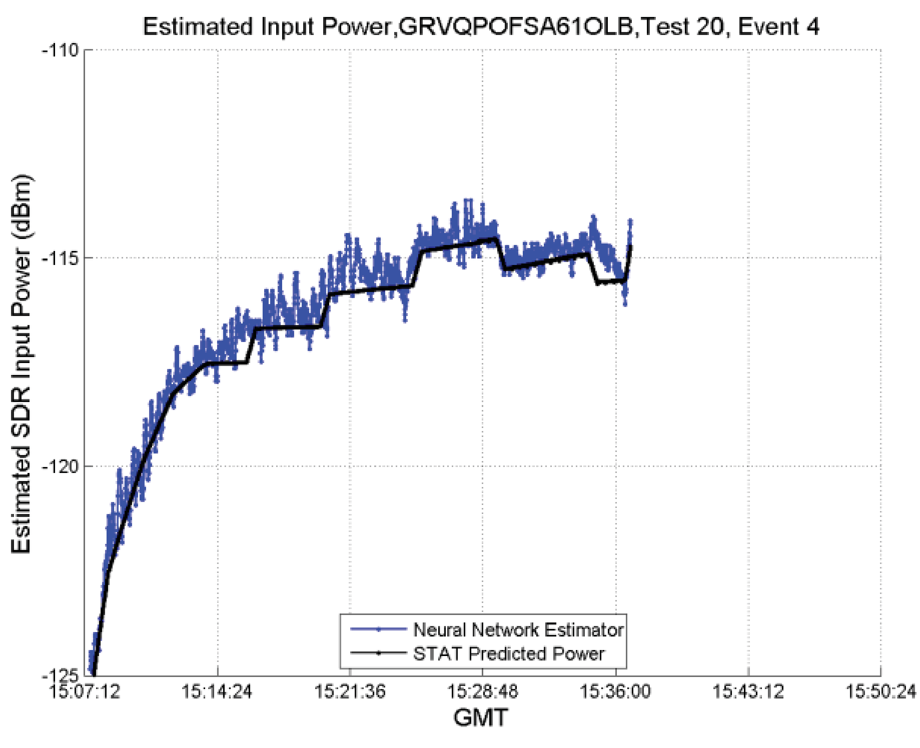

Figure 4.—Estimated and predicted received power at SDR (Profile Style 1).

Figure 5 shows the bit error rate curve obtained during the test shown in Figure 4. This style of pointing profile was designed to allow more time high power levels to obtain more accurate bit error rate data.

In order to obtain expected acquisition data, the profile style was changed as shown in Figure 6. This profile started at high powers, where a zero BER was expected, and dropped quickly to power levels below where the radio can operate. This profile style generally was designed to the exact length of the actual TDRSS event. This approach resulted in good acquisition level data, but often poor BER data for higher powers, because not enough time was spent at the higher power levels to get accurate data. Figure 7 shows the actually achieved estimated and predicted power into the SDR for an example event.

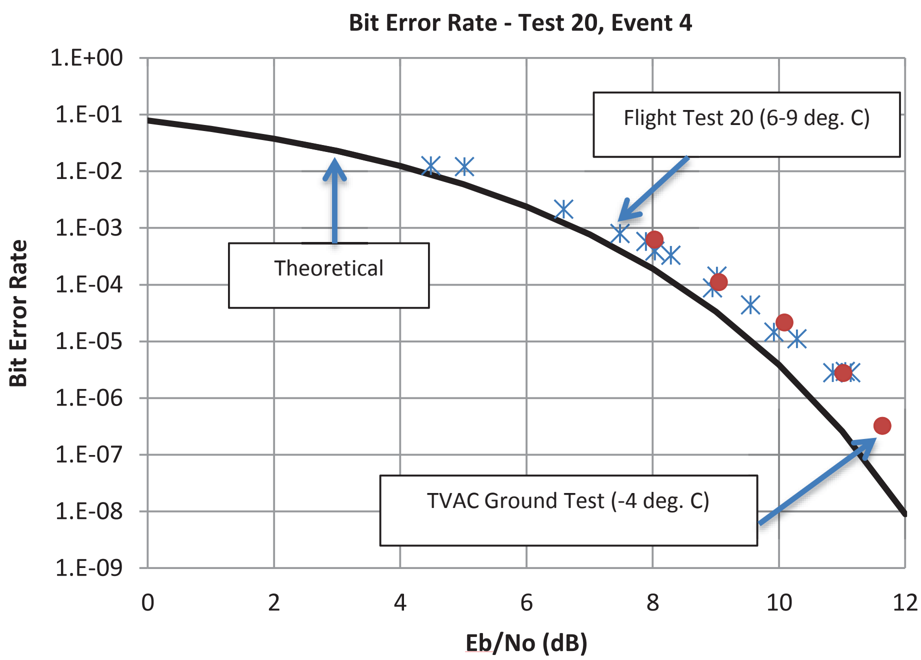

Figure 5.—Bit error rate curve (Profile Style 1).

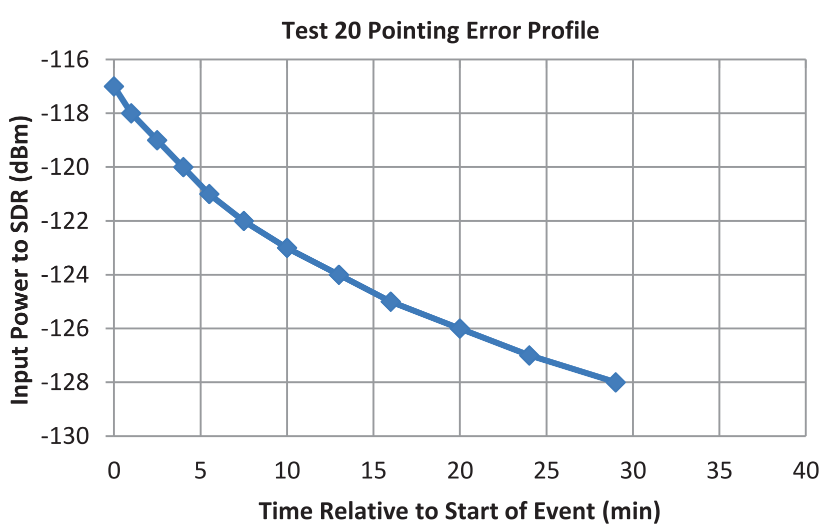

Figure 6.—Profile Style 2.

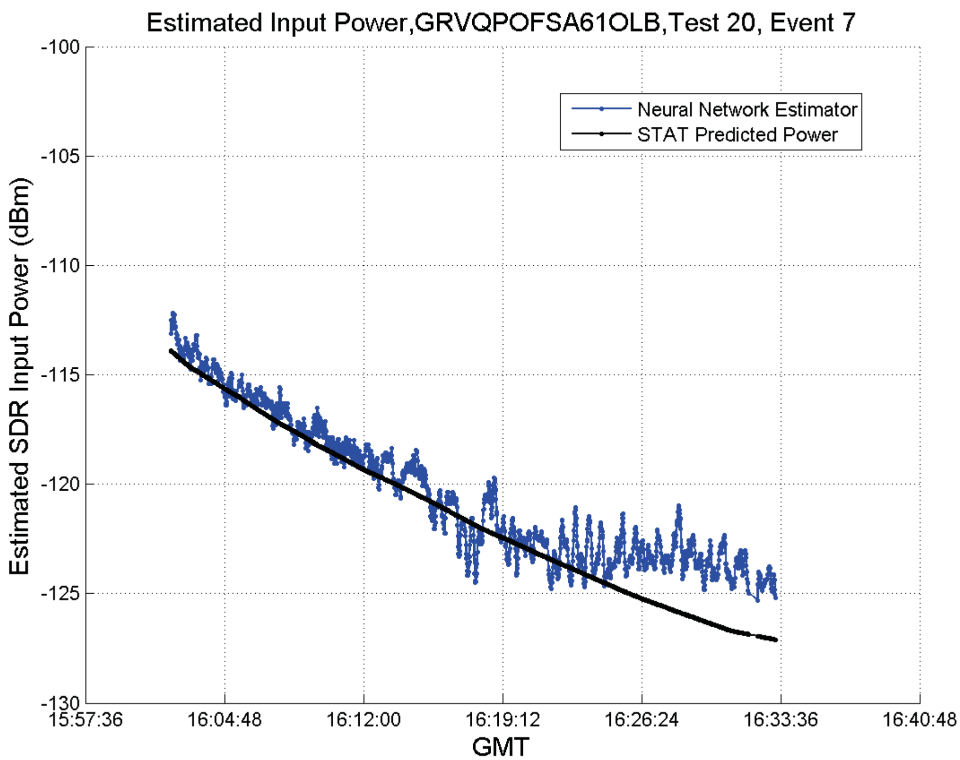

Figure 7.—Estimated and predicted received power at the SDR (Profile Style 2).

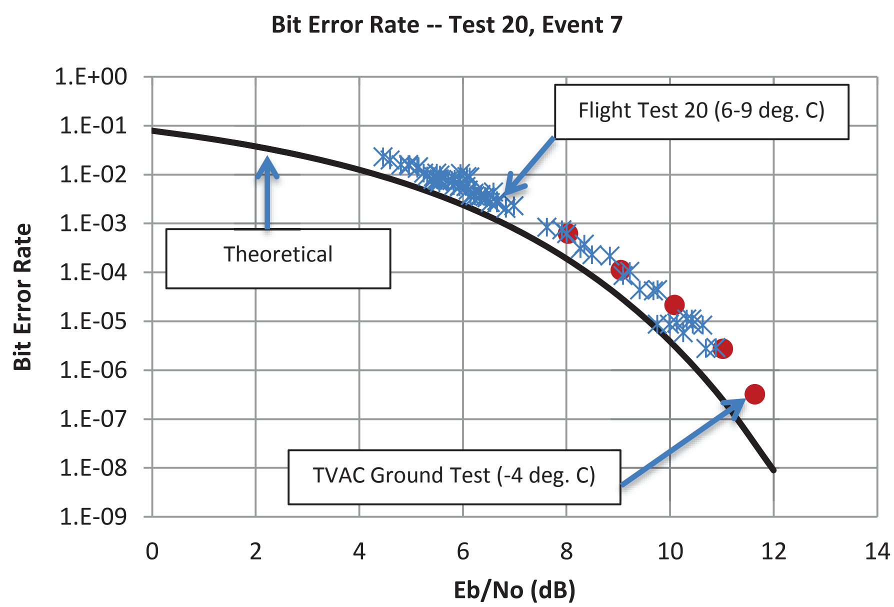

Figure 8.—Bit error rate curve (Profile Style 2).

Figure 8 shows the BER curve achieved with this type of profile for that event. Notice that the BER curve spreads out at the higher E_b/N_0 values. This is caused by the short amount of time spent in the higher power levels with this 2nd profile type.

SDR Input Power

The input power to the GD SDR was estimated using the digital and analog AGC telemetry values measured during each test. The algorithm for the power estimate was designed and verified during ground testing of the GD flight model SDR prior to launch and installation of the SCAN Testbed on the ISS. Detailed information on this power estimator and performance in estimating the SDR input power can be found in the paper entitled *SDR Input Power Estimator Algorithms* presented (by Janette Briones and Jennifer Nappier) at the IEEE Aerospace Conference at Big Sky, Montana, March 2013.

Figure 9 shows typical power levels seen at the input to the GD SDR during commissioning. Commissioning tests were designed to show a progression from "simple" to "complex" functionality and to validate the SDR technology aspects of the communication system using a single and most basic configuration. The smooth lines on the graph represent the predicted power which are calculated based on ISS location and attitude, antenna gimbal angles, TDRS attitude, TDRS pointing angles, antenna gain, and RF subsystem losses. The jagged lines are the estimated power using the digital and analog AGC values. Although they are not shown on the figure below, power levels for the MGA, 18 kbps SA and MA waveforms were similar to the corresponding center frequency at the 72 kbps data rate. In other words, the MGA power levels varied per antenna and center frequency, but were very consistent for events with the same antenna. Data rate did not affect the receive power level. The SN-LGA forward-link clearly provided much lower power to the SDR. This was expected and was due to the fact that the LGA antenna is not steerable, has lower gain, and experiences multipath effects.

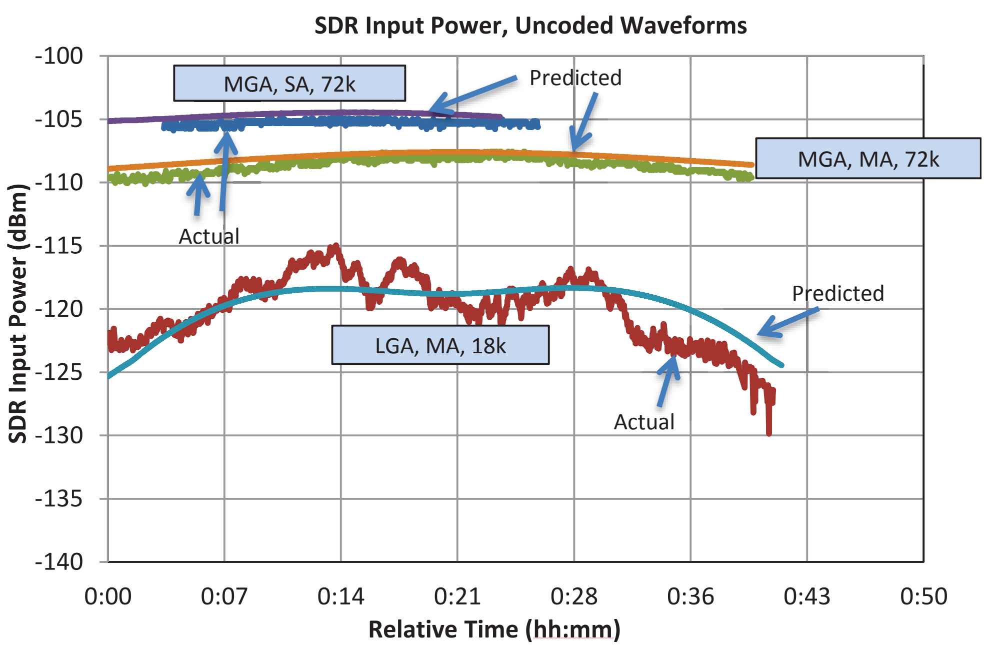

Figure 9.—SDR input power.

Receive (Forward-Link) Waveform BER Performance

The bit error rate (BER) is a key metric used to evaluate the performance of the GD SDR launch waveform. Figures 10 to 13 show typical BER curves for each on the four launch waveform tests. The BER tester accumulates a running total of received bits and received bit errors. Since the power is changing over the entire duration of the event, a total bit error rate over the event is not very meaningful. To produce a BER curve, an instantaneous bit error rate was calculated over a 20 sample interval. This instantaneous bit error rate data was then plotted against the average estimated E_b/N_0, determined from the link prediction, over the same 20 sample interval. The BER curves (shown in blue asterisks) in Figure 10 to Figure 13 are plotted against the QPSK theoretical curve and ground testing BER data for reference. The on-orbit curves are shifted to the left from the ground testing curves. This is because the ground data was acquired at ambient temperatures near 25 °C and the on-orbit data was acquired at much lower temperatures of 4 to 12 °C. The left shift of about 0.5 dB was expected based upon ground thermal vacuum testing performed at similar cold temperatures.

Figure 11 shows BER data for the only coded waveform tested. Good BER curves are difficult to acquire for coded waveforms, because low data rates require very long test times to get an accurate count of bit errors. Long tests are not possible given the short event times possible with the TDRSS network.

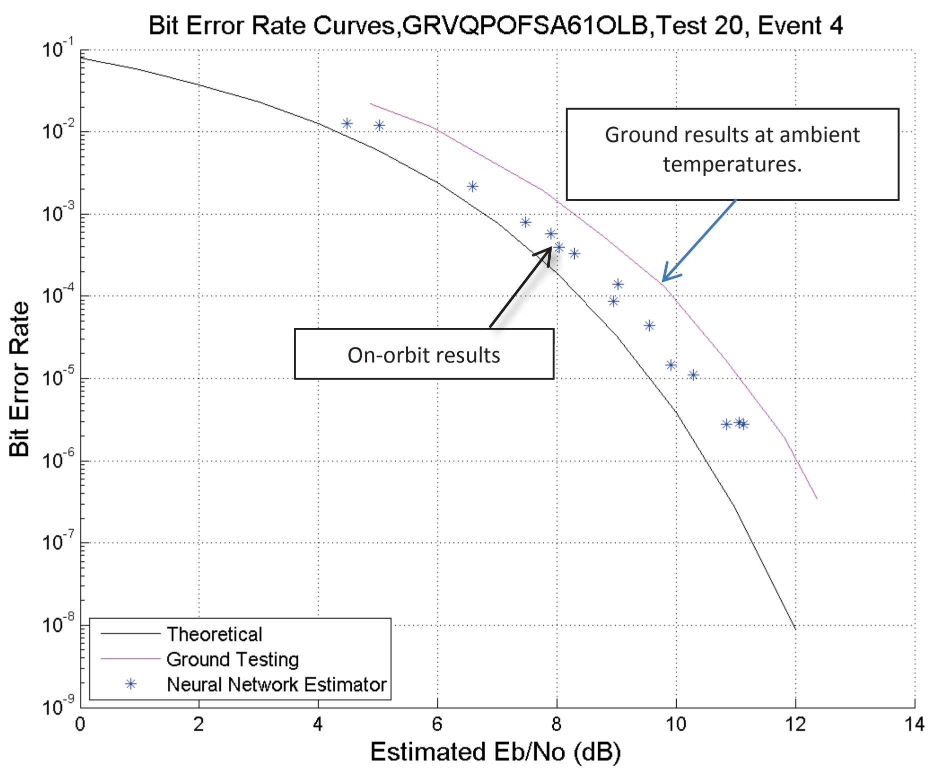

Figure 10.—Test 20: BER curve, SN-MGA, SA, 18 kbps, uncoded.

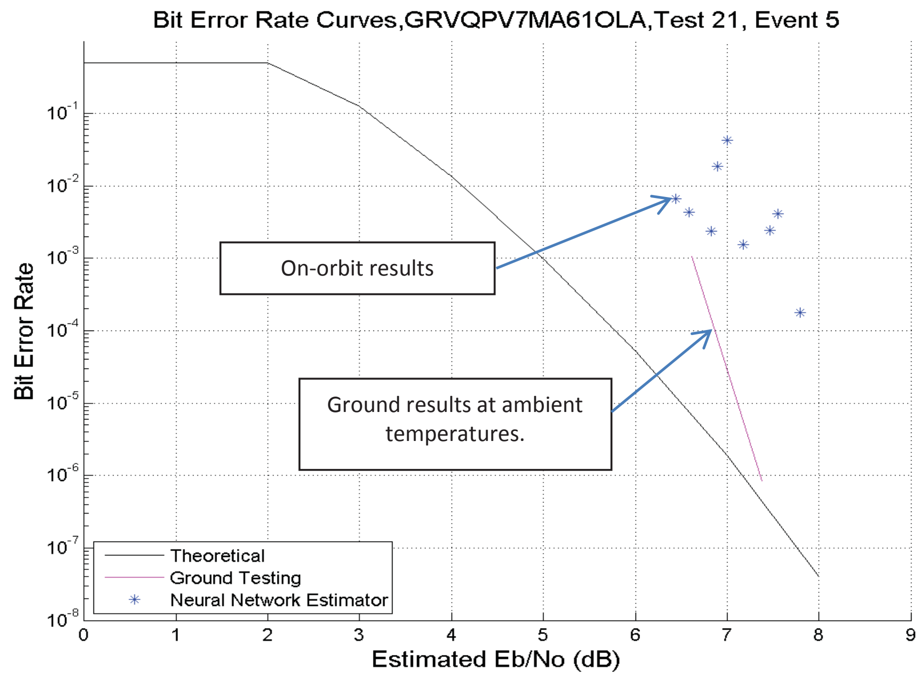

Figure 11.—Test 21: BER curve, SN-MGA, MA, 18 kbps, coded.

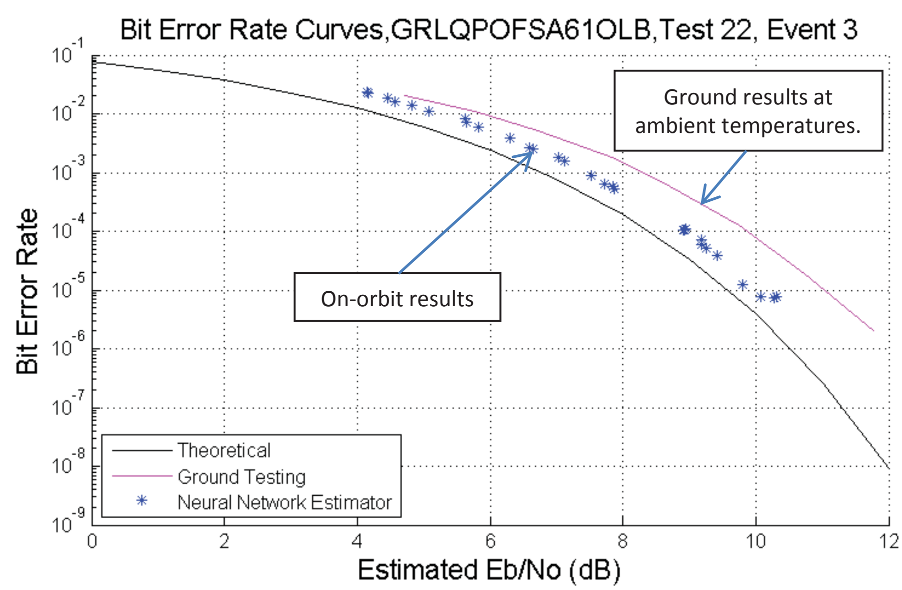

Figure 12.—Test 22: BER curve, SN-MGA, SA, 72 kbps, uncoded.

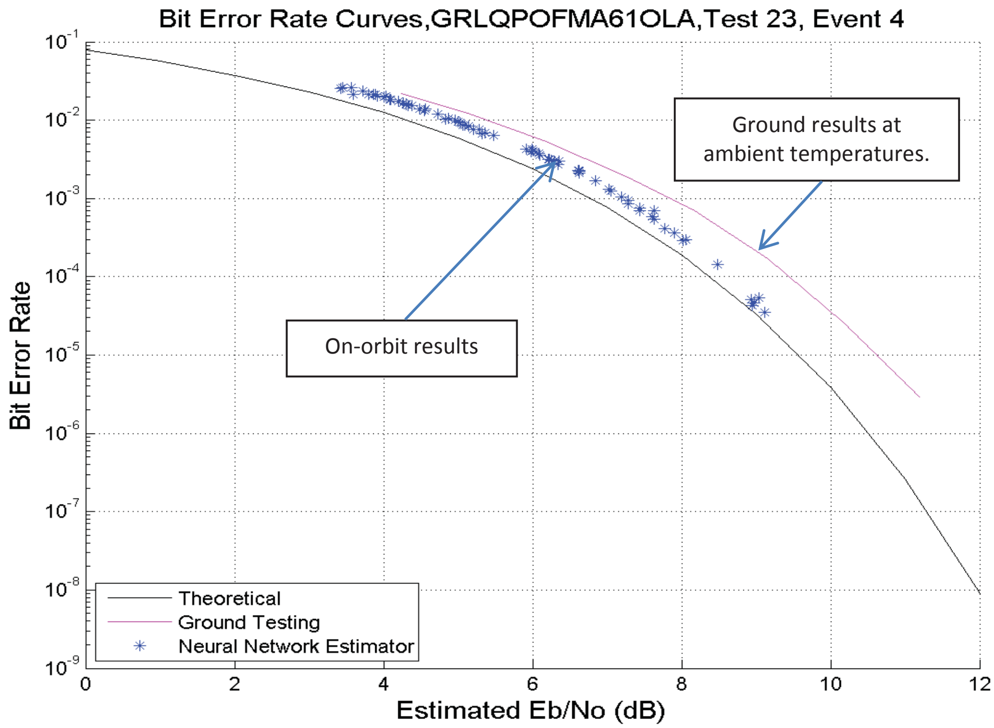

Figure 13.—Test 23: BER curve, SN-MGA, MA, 72 kbps, uncoded.

TABLE 5.—RETURN-LINK AVERAGE BIT ERROR RATES

Test		Freq.	Coherent	Forward Rate (kbps)	Return Rate (kbps)	FEC	Average BER
Test 20	Event 3	SA	No	18	24	No	2.9×10^{-3}
	Event 4	SA	No	18	24	No	1.3×10^{-3}
Test 21	Event 1	MA	No	18	24	No	2.2×10^{-4}
Test 22	Event 3	SA	Yes	72	192	No	3.0×10^{-2}
	Event 4	SA	Yes	72	192	No	3.6×10^{-2}
Test 23	All events	MA	No	18	24	No	N/A (link margin too low)

Transmit (Return-Link) Waveform BER Performance

Meaningful BER data was difficult to graph for the return-link portion of the launch waveform tests because accurate E_b/N_0 values were not available. Raw C/N_0 values, obtained from NASA White Sands Complex (WSC), were used to calculate the E_b/N_0. These C/N_0 values were not well-understood and could vary as much as 3 dB from the real C/N_0 value. The variations in the C/N_0 appear to be due to noisy E_b/N_0 measurements and data rate related calculation errors.

Since accurate E_b/N_0 values were not available, meaningful BER curves could not be plotted for the return link tests. Instead, the average BER was calculated and shown in Table 5 for a number of return link events. The average BER was dependent on the antenna off-pointing profile used for the event. Typically the transmitted power varied widely due to off-pointing and resulted in wide variations in instantaneous BER. The high E_b/N_0 portion of the pointing profile for Tests 20, 21, and 22 achieved zero bit errors.

Automatic Gain Control

The GD SDR analog and digital automatic gain control adjusts the received RF power to a constant level for receive signal processing. The response of the AGCs to changes in SDR input power and temperature is different for each receive-side waveform. The analog AGC varies with center frequency (SA/MA) as it is located in the RF module of the radio and operates independently of the radio acquisition state. The digital AGC varies with symbol rate (coding and data rate) as it is located in the FPGA. Both the analog and digital AGCs vary over temperature, but the analog AGC variation is far more significant. The AGCs scale based on total received RF power, so varying noise conditions or the presence of interferers will affect the AGC output.

The on-orbit test events were completed with GD SDR baseplate temperatures ranging typically from +4 to +12 °C. Digital and analog AGC data collected during launch waveform characterization testing are shown graphically in Figures 14 and 15. The digital AGC plots shown in Figure 14, show that the data acquired during on-orbit testing is very similar to the data acquired during ground testing. Notice that the digital AGC plots show three distinct trend lines. The trend at a given temperature shows that the digital AGC varies with the waveform symbol rate (data rate + coding). The analog AGC plots, shown in Figure 15, illustrate that the plots show two distinct trend lines. The analog AGC trend at a given temperature is dependent on the center frequency (SA or MA). The plots also show the temperature trend, due to the lower temperatures experienced on-orbit. During ground testing the data was obtained at ambient temperature and on-orbit data was obtained between 4 to 12 °C.

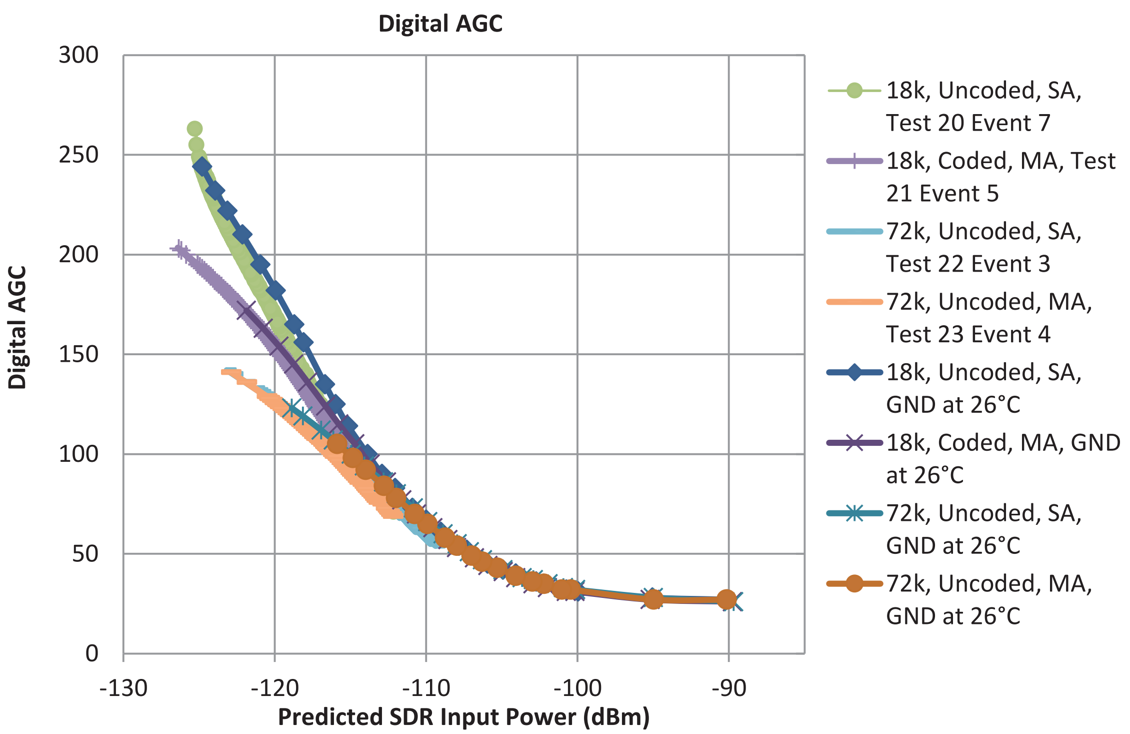

Figure 14.—Digital AGC.

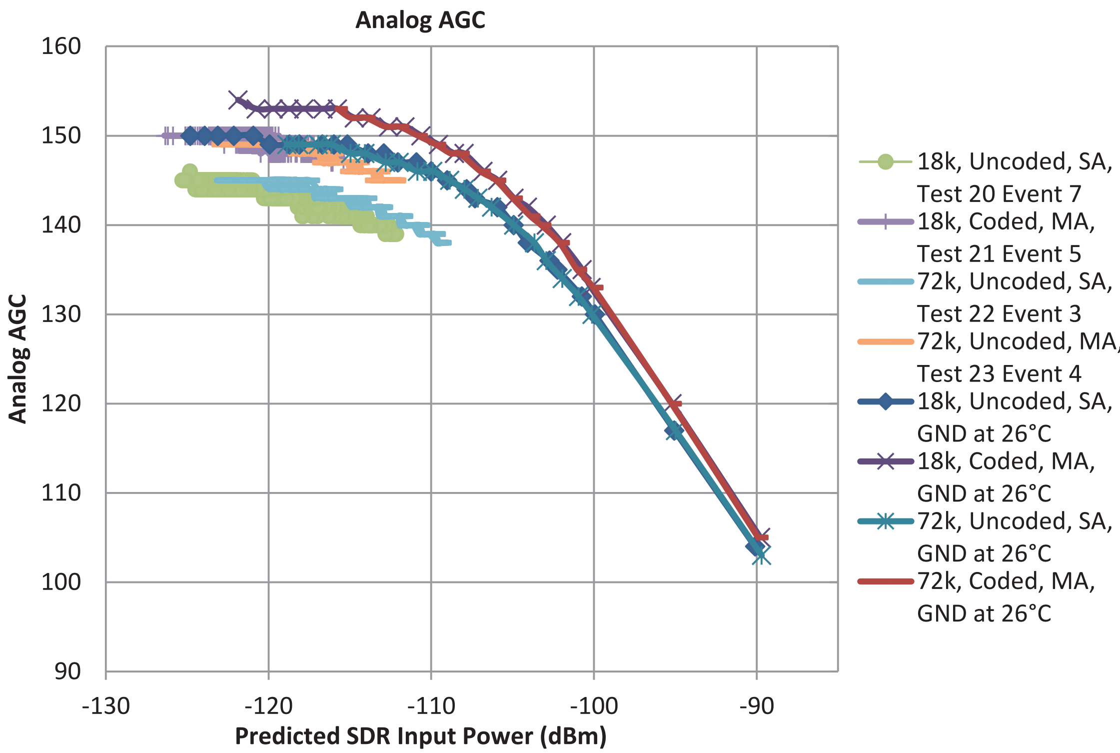

Figure 15.—Analog AGC.

Acquisition Levels

One of the goals of the launch waveform characterization tests was to determine the forward-link minimum acquisition threshold. This was done by varying the input power to the SDR using antenna off-pointing and finding the power level at which the radio reaches state 5 (i.e., acquires the short PN code) or when it transitions from state 5 to state 4 (i.e., loses the short code acquisition). State 5 is the minimum acquisition level required to receive data. A design requirement for the GD radio was to have a minimum acquisition threshold equal to or less than the following

- –118 dBm for the 18 kbps data rate
- –112 dBm for the 72 kbps data date

The acquisition threshold data listed in Table 6 is the total SDR input power at which the SDR can acquire the short code and carrier (state 5). The receiver meets the minimum acquisition threshold criteria. The acquisition threshold measured during ground testing is included for reference. The ground data was acquired at ambient temperatures. The difference between the on-orbit acquisition level and the ground acquisition was about 1.5 dB and was consistent across all four test waveforms. The cold (usually between 4 and 12° C) on-orbit temperatures results lower the acquisition power level. The lower on-orbit radio acquisition levels are due to the improved performance of the radio at lower temperatures from a lower noise figure due to lower electronic noise, as well as a lower noise floor in the space environment.

TABLE 6.—RADIO ACQUISITION LEVELS

Test Number	Antenna	Freq.	Forward Rate	FEC	Radio Acq. Level (dBm)		Result
					On-Orbit	Ground	
Test 20	SN-MGA	SA	18 k	No	–125.1	–123.9	Pass
Test 21	SN-MGA	MA	18 k	Yes	–123.7	–122.1	Pass
Test 22	SN-MGA	SA	72 k	No	–119.5	–118.0	Pass
Test 23	SN-MGA	MA	72 k	No	–120.2	–118.5	Pass

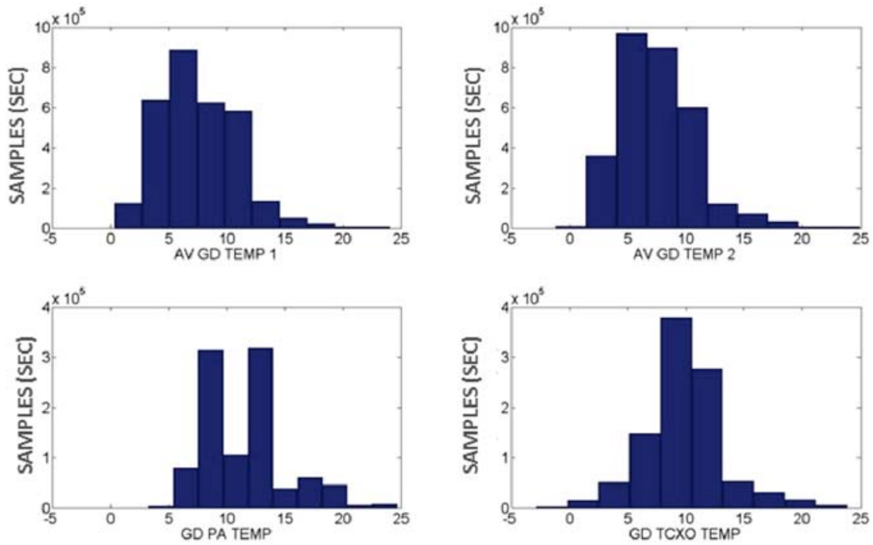

Figure 16.—Temperature histograms.

On-Orbit Temperatures

The GD SDR has four temperature sensors called GD Temp 1, GD Temp 2, GD PA Temp, and GD TCXO Temp. The sensors for GD Temp 1 and GD Temp 2 are located on the outside of the SDR on its baseplate. These sensors are connected directly to the Avionics and telemetry is available when the Avionics is power on. The other two temperature sensors, GD PA Temp and GD TXCO Temp, are located in the Power Amplifier (PA) and the temperature compensated crystal oscillator (TCXO) internal to the radio. The telemetry from these temperature sensors is sent from the GD SDR to the Avionics to be transmitted to the ground and telemetry is only available when the SDR is powered on. Figure 16 contains histograms of all four temperature sensor values over the first year of operation of the GD SDR, showing the typical on-orbit temperatures experienced by the SDR.

Future Work

Testing of GD SDR launch waveform is complete. Future testing will focus on updating the launch waveform to add a forward-link signal-to-noise ratio (SNR) estimator.

Conclusions

This report shows the on-orbit performance of the GD SDR. Every test was completed at least twice in order to verify repeatability of results. The on-orbit test results obtained during the launch waveform characterizations test were compared to results from ground testing of the flight model SDR. The on-orbit results were found to be very similar to the ground results, so the ground testing was determined to be a good predictor of on-orbit performance. All tested waveform configurations met or exceeded the expected BER performance, the SDR signal acquisition levels met the minimum acquisition criteria, the SDR input power was close to the predicted power, and the analog and digital AGC levels were as expected.

Appendix A.—GD Test Matrix

TABLE 7.—LAUNCH WAVEFORM TEST MATRIX

Test ID	Test 20: SA non-coherent, full duplex, uncoded, 18/24	Test 21: MA non-coherent, full duplex, coded, SpW, 18/24	Test 22: SA non-coherent, full-duplex, 72/192	Test 23: MA non-coherent, full-duplex, SpW, 72/192
SDR	GD	GD	GD	GD
SCAN Testbed Antenna	SN-MGA	SN-MGA	SN-MGA	SN-MGA
RF Subsystem Path	Path 2 (S1=2,S2=1,S3=1)	Path 2 (S1=2,S2=1,S3=1)	Path 2 (S1=2,S2=1,S3=1)	Path 2 (S1=2,S2=1,S3=1)
Waveform ID (Forward/Return)	182/218	183/221	206/242	208/246
Data Group	DG1	DG1	DG1	DG1
Mode	M2	M2	M2	M2
Coherency	Non-coherent	Non-coherent	Non-coherent	Non-coherent
Forward(Rx) Carrier Frequency	S SA FL (2.041 GHz)	S MA FL (2.106 GHz)	S SA FL (2.041 GHz)	S MA FL (2.106 GHz)
Return(Tx) Carrier Frequency	S SA FL (2.2165 GHz)	S MA FL (2.2875 GHz)	S SA FL (2.2165 GHz)	S MA FL (2.2875 GHz)
RF Operation @ Spacecraft	Duplex @ TDRS	Duplex @ TDRS	Duplex @ TDRS	Duplex @ TDRS
Forward(Rx) Data Rate (kbps)	18 kbps	18 kbps	72 kbps	72 kbps
Return(Tx) Data Rate (kbps)	24 kbps	24 kbps	192 kbps	192 kbps
Spacewire Mode (BER/Logging/None)	None	BER	None	BER
APS Mode	Open Loop	Open Loop	Open Loop	Open Loop
Special APS Config?	Embedded TRK errors	Embedded TRK errors	Embedded TRK errors	Embedded TRK errors
APS Logging, Period	100 ms	100 ms	100 ms	100 ms
Number of Passes	2	2	2	2
Desired Link Performance	SDR input power: –125 to –116 dBm	SDR input power: –122 to –118 dBm	SDR input power: –119 to –110 dBm	SDR input power: –119 to –110 dBm
Link Path (TDRS/GN)	F9-F10	F10	F9-F10	F10
TDRS Antenna (SA1/SA2)	Either (but documented)	SA3 / Any	Either (but documented)	SA3 / Any
TDRS Mode (S {N/H Power},Ka {P/A Track})	S - Normal Power	N/A	S - Normal Power	N/A
Tracking (Range/1W-Doppler/2W-Doppler)	1W Doppler	1W Doppler	1W Doppler	1W Doppler
White Sands SGLT Used	Any (but documented)	Any (but documented)	Any (but documented)	Any (but documented)
Link Pass Start Time	No Earlier than 11:30 GMT	No Earlier than 11:30 GMT	No Earlier than 11:30 GMT	No Earlier than 11:30 GMT
Link Pass Stop Time	No Later than 18:30 GMT	No Later than 18:30 GMT	No Later than 18:30 GMT	No Later than 18:30 GMT
Ground System Config (EFEP/SFEP)	Yes	Yes	Yes	Yes
Onboard File storage	~10 Mb	~10 Mb	~10 Mb	~10 Mb
ISS S- & Ku-Band Overlap Coverage?	Yes	Yes	Yes	Yes
Without Obscuration?	Yes	Yes	Yes	Yes
ISS BAD (Timestamped-Position, Attitude, Beta Angle, Altitude) Requested	Yes (Timestamped-Position,Attitude)	Yes (Timestamped-Position,Attitude)	Yes (Timestamped-Position,Attitude)	Yes (Timestamped-Position,Attitude)

Test ID	Test 20: SA non-coherent, full duplex, uncoded, 18/24	Test 21: MA non-coherent, full duplex, coded, SpW, 18/24	Test 22: SA non-coherent, full-duplex, 72/192	Test 23: MA non-coherent, full-duplex, SpW, 72/192
Test Measurement at Ground Requested	No	No	No	No
SNAS Data Requested	SN Delog, UPD	UPD	SN Delog, UPD	UPD
TDRS/GN Measured EIRP Requested	Yes	Yes	Yes	Yes
Additional Notes	In order to do acquisition threshold test, starting power must be less than -125 dBm; no need to wait until forward acquisition to transmit	In order to do acquisition threshold test, starting power must be less than -122 dBm; no need to wait until forward acquisition to transmit	May need change TDRS power or STB antenna to achieve desired SDR input power range; In order to do acquisition threshold test, starting power must be less than -119 dBm; no need to wait until forward acquisition to transmit	May need change TDRS power or STB antenna to achieve desired SDR input power range; In order to do acquisition threshold test, starting power must be less than -119 dBm; no need to wait until forward acquisition to transmit
Success Criteria	Verify acquisition threshold; verify BER curves; verify AGC levels	Verify acquisition threshold; verify viterbi threshold; verify AGC levels	Verify acquisition threshold; verify BER curves; verify AGC levels	Verify acquisition threshold; verify BER curves; verify AGC levels